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**Hybrid Fuzzy- Proportional Integral Derivative Controller
(F- PID-C) for Control Speed of Brushless Direct Current
Motor (BLDCM)**

ACADEMIC SESSION: 2017/2018

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HYBRID FUZZY- PROPORTIONL INTEGRAL DERIVATIVE
CONTROLLER (F-PID-C) FOR CONTROL OF SPEED
BRUSHLESS DIRECT CURREN MOTOR (BLDCM)

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A thesis submitted in
fulfilment of the requirement for the award of the
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Dedicated with gratitude to my country Libya for the huge support and giving me this opportunity to study overseas.



PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

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ABSTRACT

Hybrid Fuzzy proportional-integral-derivative (PID) controllers (F-PID-C) is designed and analyzed for controlling speed of brushless DC (BLDC) motor. A simulation investigation of the controller for controlling the speed of BLDC motors is performed to beat the presence of nonlinearities and uncertainties in the system. The fuzzy logic controller (FLC) is designed according to fuzzy rules so that the systems are fundamentally robust. There are 49 fuzzy rules for each parameter of FUZZY-PID controller. Fuzzy Logic is used to tune each parameter of the proportional, integral and derivative (k_p, k_i, k_d) gains, respectively of the PID controller. The FLC has two inputs i.e., i) the motor speed error between the reference and actual speed and ii) the change in speed of error (rate of change error). The three outputs of the FLC are the proportional gain, k_p , integral gain k_i and derivative gain k_d , gains to be used as the parameters of PID controller in order to control the speed of the BLDC motor. Various types of membership functions have been used in this project i.e., gaussian, trapezoidal and triangular are assessed in the fuzzy control and these membership functions are used in FUZZY PID for comparative analysis. The membership functions and the rules have been defined using fuzzy system editor given in MATLAB. Two distinct situations are simulated, which are start response, step response with load and without load. The FUZZY-PID controller has been tuned by trial and error and performance parameters are rise time, settling time and overshoot. The findings show that the trapezoidal membership function give good results of short rise time, fast settling time and minimum overshoot compared to others for speed control of the BLDC motor.

ABSTRAK

Pengawal (F-PID-C) Hibrid Kabur berkadar-kamiran-terbitan (PID) direka dan dianalisis bagi mengawal kelajuan motor DC (BLDC) tanpa berus. Suatu penyiasatan simulasi bagi pengawal yang mengawal kelajuan motor BLDC dijalankan untuk menghalang kewujudan ketidaklinearan dan ketidakpastian di dalam sistem. Pengawal logik kabur (FLC) direka berdasarkan peraturan kabur supaya sistem-sistem teguh pada dasarnya. Terdapat 49 peraturan kabur bagi setiap parameter pengawal FUZZY-PID. Logik kabur digunakan untuk menala setiap parameter bagi gandaan-gandaan berkadar, kamiran dan terbitan (k_p, k_i, k_d), masing-masing bagi pengawal PID. FLC mempunyai dua input iaitu, i) ralat kelajuan motor antara rujukan dan kelajuan sebenar, dan ii) perubahan dalam kelajuan daripada ralat (kadar bagi ralat perubahan). Tiga output daripada FLC iaitu gandaan berkadar; k_p , gandaan kamiran; k_i dan gandaan terbitan; k_d , gandaan-gandaan akan digunakan sebagai parameter bagi pengawal PID dalam mengawal kelajuan motor BLDC. Pelbagai jenis fungsi keahlian telah digunakan dalam projek ini seperti Gaussian, trapezoid dan bersegi tiga dinilai dengan kawalan kabur dan fungsi keahlian ini digunakan dalam FUZZY PID bagi analisis perbandingan. Fungsi-fungsi keahlian dan peraturan-peraturan telah ditakrifkan menggunakan editor sistem kabur yang diberi dalam MATLAB. Dua situasi yang berbeza telah disimulasikan, iaitu sambutan mula, sambutan langkah dengan beban dan tanpa beban. Pengawal FUZZY-PID telah ditala dengan kaedah cuba-cuba dan prestasi parameter, iaitu masa naik, masa pengenapan dan lajukan. Dapatan menunjukkan fungsi keahlian trapezoid memberikan keputusan baik bagi masa naik yang pendek, masa pengenapan yang pantas dan lajukan minimum dibandingkan dengan yang lain-lain bagi kawalan kelajuan motor BLDC.

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LIST OF SYMBOLS AND ABBREVIATIONS

<i>BLDCM</i>	- Brushless Direct Current Motor
<i>FLC</i>	- Fuzzy Logic Controller
<i>PID</i>	- Proportional Integral and Derivative
<i>F-PID-C</i>	- Fuzzy- Proportional Integral and Derivative- Controller
<i>EMF</i>	- Electromotive Force
<i>PSO</i>	- Particle swarm optimization
<i>MF</i>	- Membership Functions
<i>DC</i>	- Direct Current
<i>AC</i>	- Alternative Current
<i>PMSM</i>	- Permanent Magnet Synchronous Motor
<i>PWM</i>	- Pulse Width Modulation Techniques
T_p	- Peak Torque
T_R	- Rated Torque
<i>SISO</i>	- Single-Input-Single-Output
<i>MIMO</i>	- Multi-Input-Multi-Output
C_1	- Controller
C_2	- Plant
Z	- Sensor
$C_1(s)$,	- Transfer Function Elements
$C_2(s)$,	- Transfer Function Elements
$Z(s)$	- Transfer Function Elements
$y(t)$	- The Measured Output)
$r(t)$	- The Desired Output
$e(t)$	- Tracking Error
k_p	- Proportional Gain
k_i	- Integral Gain
k_d	- Derivative Gain

$C(s)$	- Correcting Terms
$MV(t)$	- Manipulated Variable
P_{out}	- Output Proportional Term
I_{out}	- Output Integral Term
D_{out}	- Output Derivative Term
τ	- A dummy Integration Variable
t	- Time or Instantaneous Time
V_{al3}, V_{al1}	- Membership Boundaries of Triangular
V_{al2}	- Membership Boundaries of Triangular
V_{al1}, V_{al3}	- Membership Boundaries of Trapezoidal
V_{al2}, V_{al4}	- Membership Boundaries of Trapezoidal
X_p	- The Midpoint
w	- The Width of Bell Function
$\mu(u_i)$	- Bell Membership Function
P_B	- Positive Big
N_B	- Negative Big
N_S	- Negative Small
Z	- Zero
N_M	- Negative Medium
P_S	- Positive Small
P_M	- Positive Medium
MAX	- Max Criterion Method)
COA	- Centroid Method or Center of Area Method
U_o	- Final Output
$v_{bs}, v_{cs},$	- Phase Voltages
R_a, R_b, R_c	- Stator Resistance Per Phase
i_a, i_b, i_c	- Stator Phase Currents
e_a, e_b, e_c	- The Phase Back Electromotive Forces
L_{ab}, L_{bc}	- Mutual Inductances Between Phases a, b and c
D	- Differential Operator
T_e	- Electromagnetic Torque (N · m)
ω	- Motor's Mechanical Angular Velocity (rad/s)
n_p	- Rotor Pole Pairs.

T_l	- Load Toque
J	- Rotor Moment of Inertia
R_N	- Number of Rules =, and =
M	- Number of Membership Functions
N	- Number of Inputs
Ce	- Change of Error
e	- Error
t_s	- Settling Time
m_p	- Rise Time
t_r	- Overshot



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CHAPTER 1

INTRODUCTION

1.1 Background

Motor drives with high performance efficiency are vital in several industries and have found application in many areas such as electric automotive, robotics, rolling mills, aviation, electric trains, and robotics [1]. Electric motors in different forms have been suggested for use in applications [2], among which the DC motors stands out. Contrarily, there are several disadvantages of the conventional DC motor, including the need for a routine maintenance of the commutators, high initial cost, and frequent changing of the brushes [3].

The conventional DC motors are not ideal in explosive or clean environments. An alternative to the DC motor is the Squirrel cage induction motor which more robust and commands an initial low cost. Meanwhile, a low power factor and starting torque are the major problems of the Squirrel cage induction motor [4]. Additionally, both the induction and conventional DC motors are not suitable for high-speed use. Another alternative to the DC and induction motors for high speed application is the brushless DC motors. The brushless DC motor is notorious for high speed usage [4]. There are several advantages of the BLDC motors over brushed DC motor; these include having longer life, immunity to noise, higher efficiency, relatively small, requiring less maintenance since there are no brushes, and

commutator arrangement. The BLDC, as the name suggests, uses electronic commutation for commutation instead of brushes, which makes it a virtually [5]. There are other advantages of the BLDC motor over the induction motor, including having a better speed - torque characteristics, longer operating life, high dynamic response, and operating noiselessly, which made it a dominant electric motor [6].

1.2 Problem statement

BLDC motors require suitable speed controllers to accomplish desired level of performances. Normally, proportional integral and derivative (PID) controller is used for the control of the speed. Though the conventional PID controllers are mostly used industrially owing to the simple structure of their operation and ease of implementation, they pose problems in the presence of control technique like sudden change in setpoint and, parameter variation (k_p, k_i, k_d) not produce automatically and these parameters need to tune, it makes the PID control gives poor response, and nonlinearity, the non-linearity arises due to armature current limitation and change in loads. Furthermore, the PID controller is difficult to tune the parameters and get satisfied control characteristics [7].

Being that BLDC motors have nonlinear model, the PID controllers are not ideal to be used. In addition, traditional PID controller cannot be used in systems with unstable parameters because the PID constant will be required to be changed often [4]; also, the BLDC motor may cause serious overshoots because it has high start torque which are not desired in most conventional controllers like PID. In this way, the BLDC motor drives system need appropriate controllers like the fuzzy PID controllers (F-PID-C) to govern the startup response, decrease overshoot and steady-state error to meet the system demands [8].

The F-PID-C is an extension of the conventional technique because of its maintenance of the linear structure of PID controllers. The F-PID-C was designed based on the basic F-PID-C principle to achieve a good controller with analytical formulas like the other smart controllers. The F-PID-C has variable control gains within their linearity structure which are nonlinearity functions of the error and the rate of changes in the error signals. They can improve the overall performance of the

BLDC motor owing to their characteristic features such as the self-tuned mechanisms which can adjust to error variations and rate of error changes caused by time delay, nonlinearity and process uncertainties [9].

In this research, three types of membership functions (MF) of F-PID-C model for the control of BLDC motor will be designed and compared between each other to achieve the best model.

1.3 Research Objectives

The study objectives are:

- i. To analyze the transient characteristics of BLDC motor, i.e., by overshoot amplitude, steady-state error and rise time using Fuzzy-PID controller based on three types of membership functions, i.e., Gaussian, Trapezoidal and Triangular.
- ii. To compare between three different types of MF by Fuzzy PID control on the BLDC motor.
- iii. To compare between two controller Fuzzy-PID controller and Fuzzy-PI controller

1.4 Scope of Project

- i. Using Simulink in MATLAB to implement fuzzy PID controller to control the speed of the BLDC motor.
- ii. Design three type of Membership functions and rules using Fuzzy Toolbox in MATLAB.
- iii. Simulation of the BLDC motor model on a MATLAB Simulink platform and developed FLC system.

CHAPTER 2

FUZZY-PID CONTROLLER CONCEPT AND BLDC MOTOR ASPECTS REVIEW

2.1 Introduction

This chapter describes the literature review of BLDC motor, PID controller and Fuzzy logic control system. In this chapter, also will discuss some researches that are relevant to this project to demonstrate continuity from the previous researches.

2.2 Previous case study

The speed and current controllers of BLDC motor with non-sinusoidal (trapezoidal) back-electromotive force have been investigated previously [10]. Faster drives with reduced ripples in current and torque and smoother speed response are often desired. In many applications, BLDC motors are controlled using back EMF. This work implements a simple control scheme which have no need any complicated calculation, or knowing the back EMF and shape functions. To address the issues of the conventional PID speed controllers, the Fuzzy logic speed controller is being set forth for the reduction of the starting current, elimination of torque overshoot, and

achieving a fast speed response. The design is simple and does not require any complex computation. Simulation studies were conducted to validate the effectiveness of the proposed system in controlling the performance of BLDCM. A robust control was achieved with the proposed algorithm via MATLAB simulation.

An adaptive F-PID-C for controlling the speed of DC brushless motor has a wide industrial application, such as in the servo motor drives, automobile, medical, and aerospace has been studied [11]. There are many advantages of the electronically commutated BLDC motors over the brushed DC motor, such as having longer life, lower volume, increased efficiency, and higher torque. This study employed Simulink model to analyze the performance of F-PID-C and adaptive F-PID-C. The tuning and computation of parameters using the normal PID controllers is difficult and when compared to the adaptive fuzzy PID controllers, does not produce satisfactory control features. The simulation studies verified a better performance of the adaptive F-PID-C compared to the F-PID-C. The BLDC motor was modelled and controlled using the SIMULINK software package.

A new P-fuzzy self-adaptive PID intelligent method based on the BLDC motor mathematical model has been proposed [12] for the control of the speed of a servo system. In the BLDC motor control system, current hysteresis is applied in the current loop, while the P and fuzzy self-adaptive PID hybrid control scheme is applied in the speed loop. To organically combined the blocks, a double close loops timing system with current hysteresis and fuzzy speed control was tested and the simulation results showed that the system has an improved accuracy, reduced response time, controlled overshoot, achieved fine robustness, was self-adapting, and obviously performed better compared to the ordinary proportional-integral, differential (PID) control. The model was validated and verified, and thus, a novel approach was provided for further motor studies.

An optimized fuzzy logic controller based on the particle swarm optimization (PSO) for the control of DC motor speed has been proposed [13]. The simulation of the controller model was carried using MATLAB software and tested on a laboratory DC motor experimentally. The performance of several controllers such as fuzzy logic controllers, PID controllers, and optimized fuzzy logic controllers was compared as well. Simulation and experimental results showed that the suggested fuzzy logic control (FLC) and PSO speed controllers had better dynamic performance compared to the normal FLC and PID controllers. Furthermore, it had a better performance on

the DC motor with a perfect speed tracking devoid of overshoots. With heuristically defined MF, the optimized membership functions (MF) offered a better performance and higher robustness compared to the regular fuzzy model. Furthermore, the ability of proposed FLC under sudden load torque changes which can result in speed variances was experimentally verified.

2.3 Brushless direct current motors (BLDC)

Several applications demand electric motors with a range of speed and torque control and the DC machine met these criteria though it needs a periodic maintenance. Like the induction and brushless permanent magnet motors, the AC machines have no brushes and are designed with robust rotors due to the absence of a commutator and/or rings, meaning a very low maintenance is required. The efficiency and power-to-weight ratio are also enhanced by this arrangement. Flux control that offers a high dynamic performance has been designed for induction motors in some applications, such as in electric traction. However, this is still a sophisticated and complex control system [14].

The hardware of most application controls has been simplified through the development of the machines with brushless permanent magnets. There are currently two types of machines with brushless permanent magnet, of which the most popular is the permanent magnet synchronous motor (PMSM), which is supplied with sinusoidal currents. The second type is the brushless DC (BLDC) motor which is supplied with quasi- square-wave currents. In these two designs, the rotor copper losses are eliminated, giving a high peak efficiency when compared to the conventional induction motor [15].

2.3.1 The development and operation strategy of the BLDC motor

The BLDC motor is a form of motor in which the magnetic field from the stator and the rotor twirls are equal in frequency (synchronous motor). The “slip” that is common with the induction motors is not experienced in the BLDC motors. The magnet rotor and wire -wound stator poles are permanently built in the BLDC motor [16].

2.3.1.1 Stator

The BLDC motor stator has a stacked steel laminations with windings which are maintained in the axially cut slots along the inner surface Figure 2.1. There are 3 stator windings in most BLDC motors which are interlinked in a star fashion and these windings are generated from various coils that are linked to derive a winding. Windings are formed from one or more interconnected coils and maintained in the slots; each winding is distributed over the stator periphery to form an even number of poles [16].



Figure 2.1: The stator of BLDC motor [16]

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